RWI Leibniz-Institut für Wirtschaftsforschung

A SLIPPERY SLOPE:

TOPOGRAPHIC VARIATION AS AN INSTRUMENTAL VARIABLE

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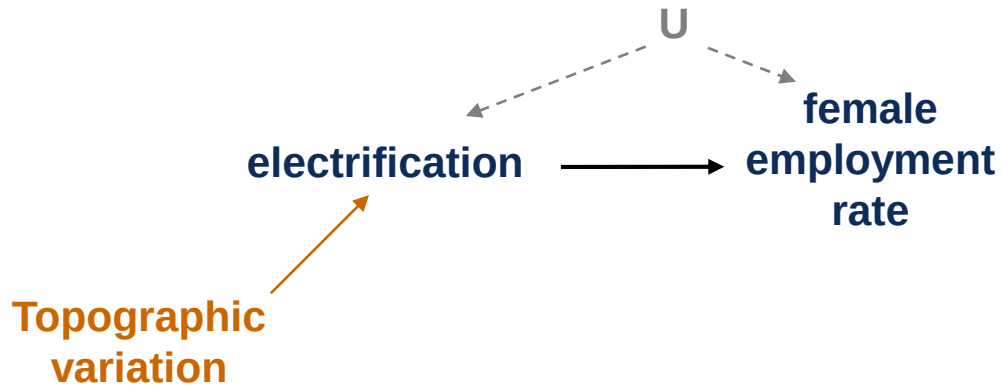
Motivation

- **Topographic variation**: measures of elevation changes, land slope, ruggedness…
  - Arguably **exogenous** to any social behavior and political decision making

- **Popular Instrumental Variable** (IV) for impact evaluations of hard-to-evaluate policy interventions, e.g energy-infrastructure (Dinkelman 2011, Duflo & Pande 2007, Mian & Sufi 2011)

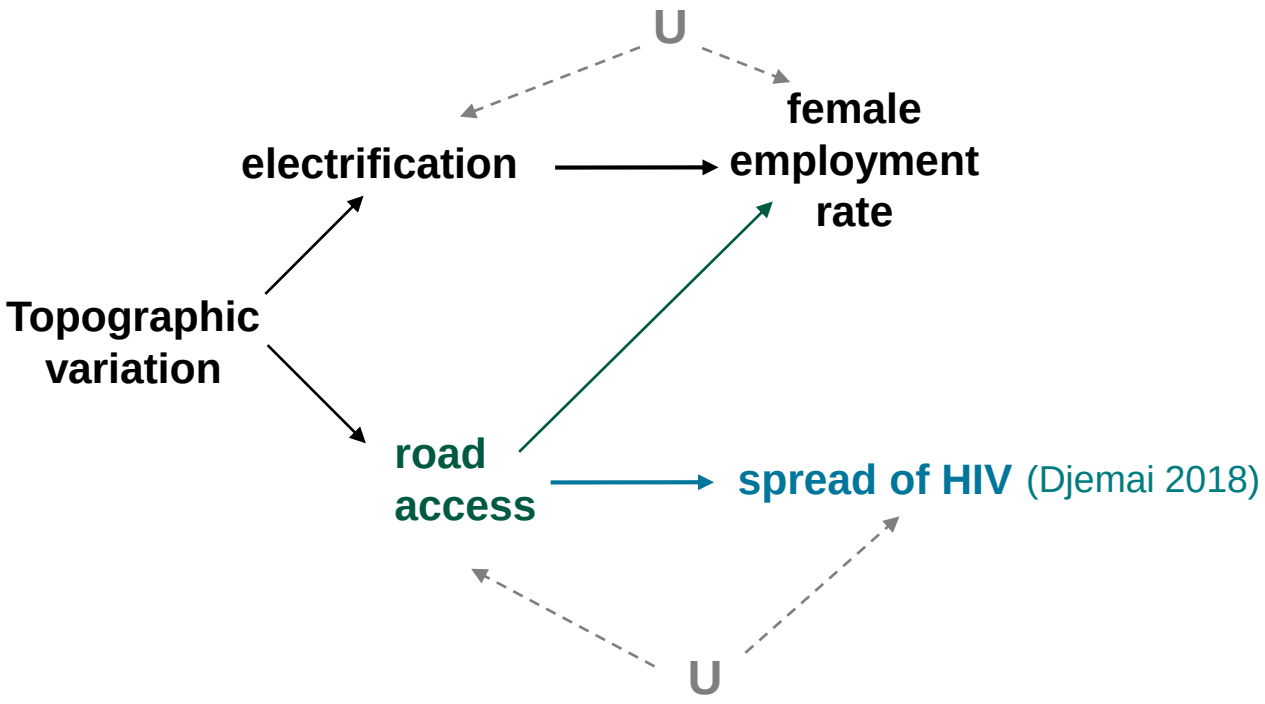
Running example: Dinkelman‘s electrification effects on employment in rural South Africa (2011, AER)



Idea:
Exploit topographic variation as a natural experiment

Motivation

The Exclusion Restriction



In this setup, instrumenting for electrification and road access is mutually exclusive.

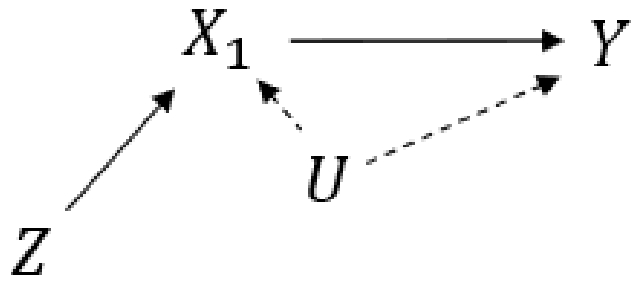
→ Repeated use of the same instrument in different contexts likely renders the instrument invalid (Gallen 2023, Mellon 2024)

→How problematic is the repeated use of similar IVs in general?

- Theoretical framework
  1. Exclusion Restriction violations
  2. Post-instrument bias

THEORETICAL FRAMEWORK

1. Recap: Basic IV model using the DAG framework (Pearl 2009)



For Dinkelman (2011):

X = electrification
Y = female employment rate
Z = land gradient
U = unobservables

Identifying assumptions:

1. IV-relevance: **Cov(X_1, Z) ≠ 0**

2. IV-validity: **Cov(U, Z | X_{exo}) = 0**

› IV's Unconfoundedness

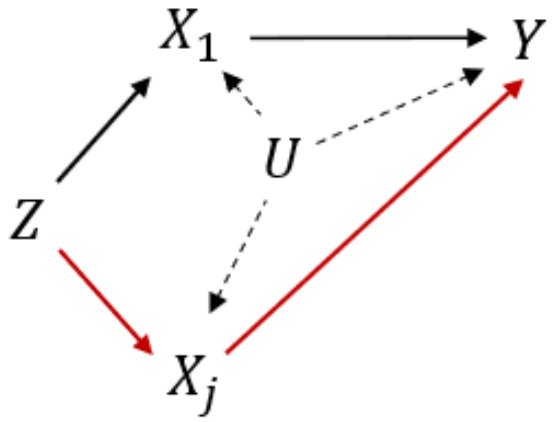
› **Exclusion Restriction**

→ There should be no effects ***unmediated*** through the treatment **X_1** !

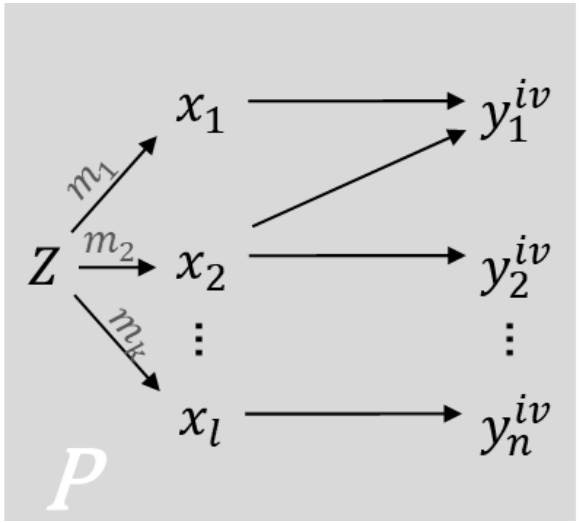
THEORETICAL FRAMEWORK

1. Exclusion Restriction violations

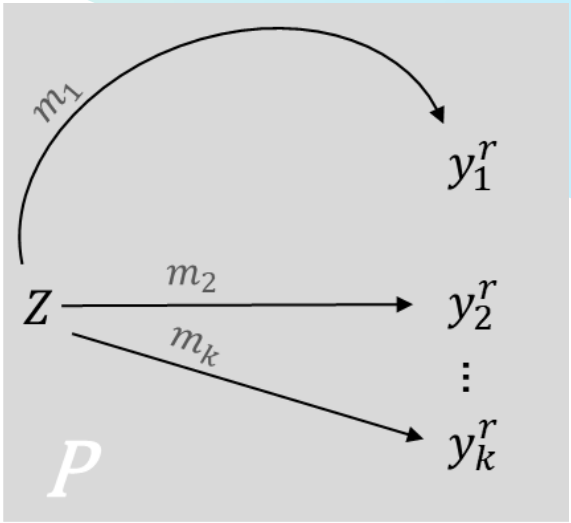
a) Exclusion restriction violation by Xj



b) Repeated IV-use in the literature



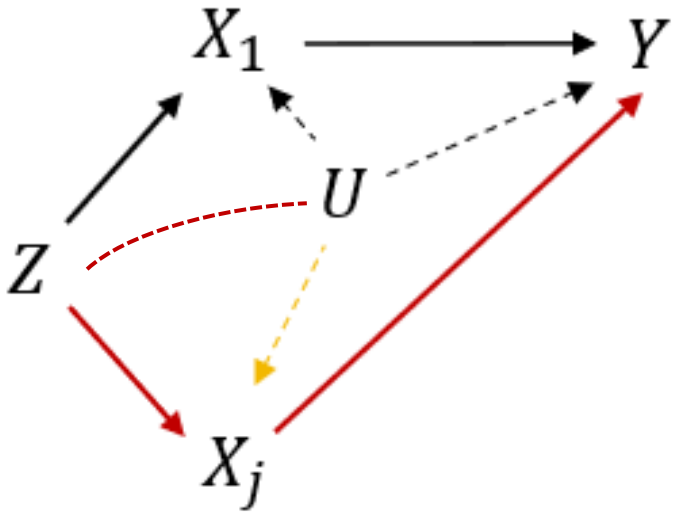
c) Multiple non-IV studies on reduced-form effects



THEORETICAL FRAMEWORK

2. Post-instrument bias

(a) X_j is a collider



For Dinkelman (2011):

X = electrification
Y = female employment rate
Z = land gradient
Xj = road access
U = business potentials

› **Conventional practice:** Block exclusion restriction variables by conditioning on them (Felton & Steward 2022)

Problem:

› Controlling for **X_j** introduces "**post-instrument bias**" (Deuchert & Huber, 2017; Glynn et al., 2023)

→ similar to a **"bad-control" problem** in OLS

› **Resembles a catch-22**:

Omitting **X_j** is inappropriate, but including **X_j** as covariates **violates** the **IV's exogeneity** requirement

Do we see a repeated use of topographic IVs?

- Systematic literature review
  1. The causal web of Topographic variation
  2. Prevalence of post-instrument bias
  3. Co-occurrence with weak IVs

SYSTEMATIC LITERATURE REVIEW

Eligibility Criteria

1. **IV studies using topographic instruments** (elevation changes, terrain slope, ruggedness…)
   → **corr = 0.6 – 0.95** (Amatulli et al., 2018)

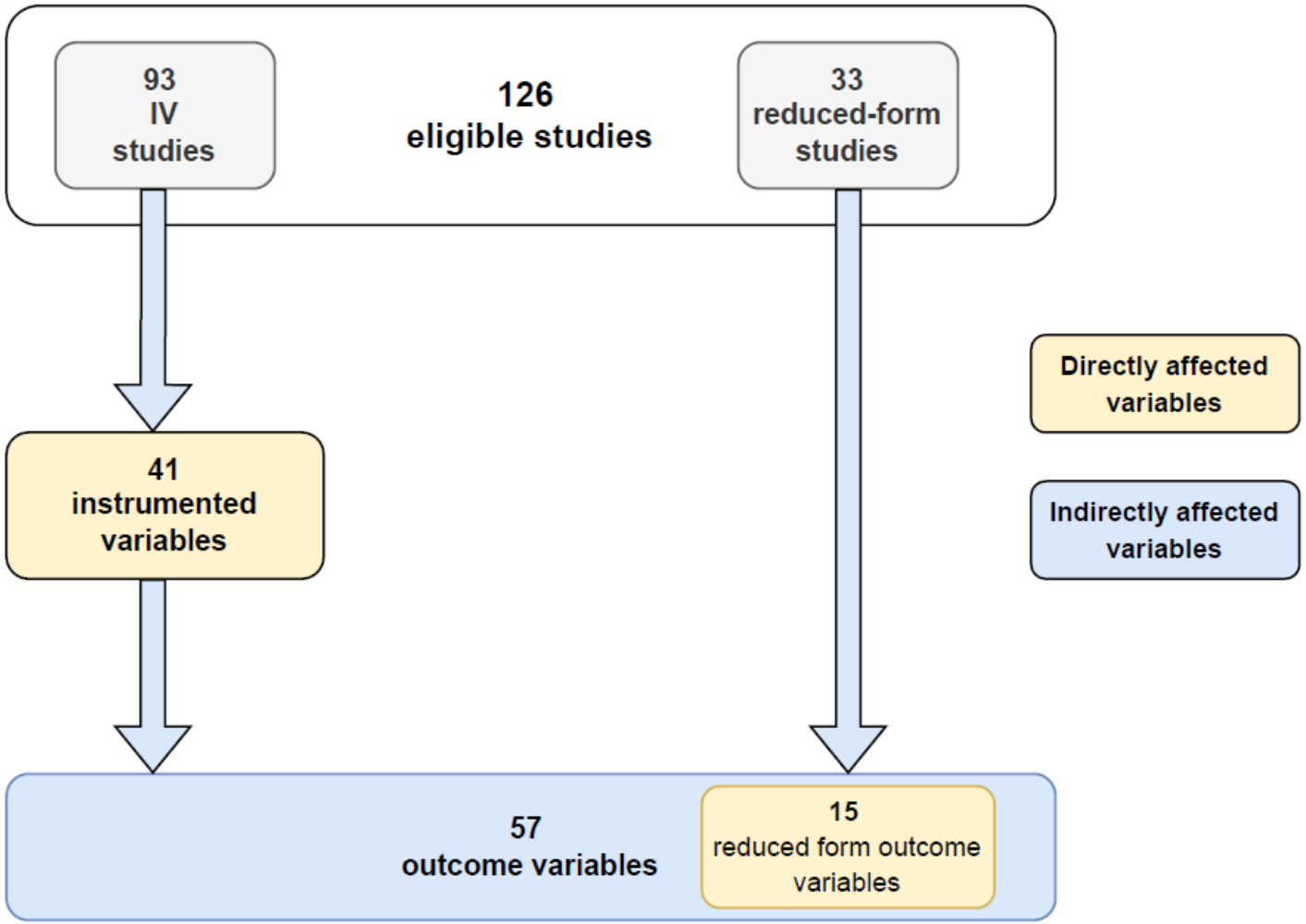
2. **“Reduced-form“ articles** that assign a **direct effect** of topography on outcomes

3. Published between **2012 and 2021**

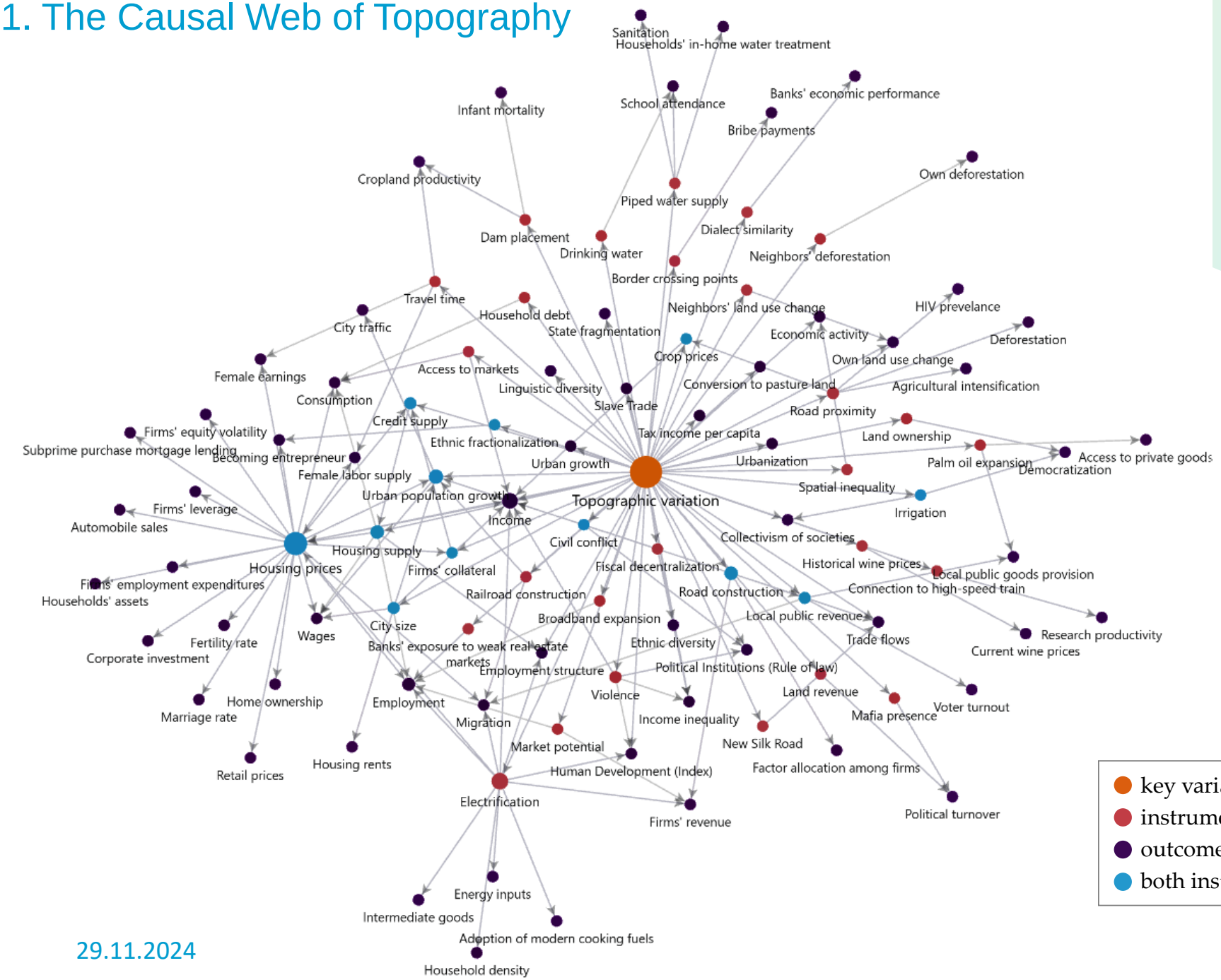
4. Published in **Top120 Economics journals**

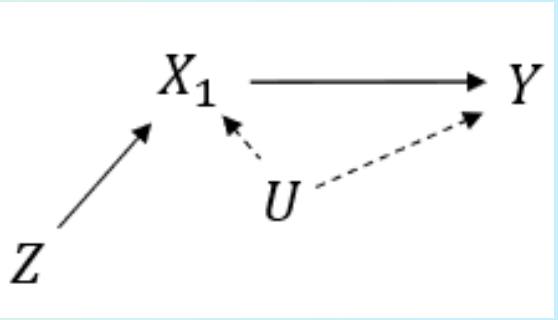
SYSTEMATIC LITERATURE REVIEW

1. Results



1. The Causal Web of Topography



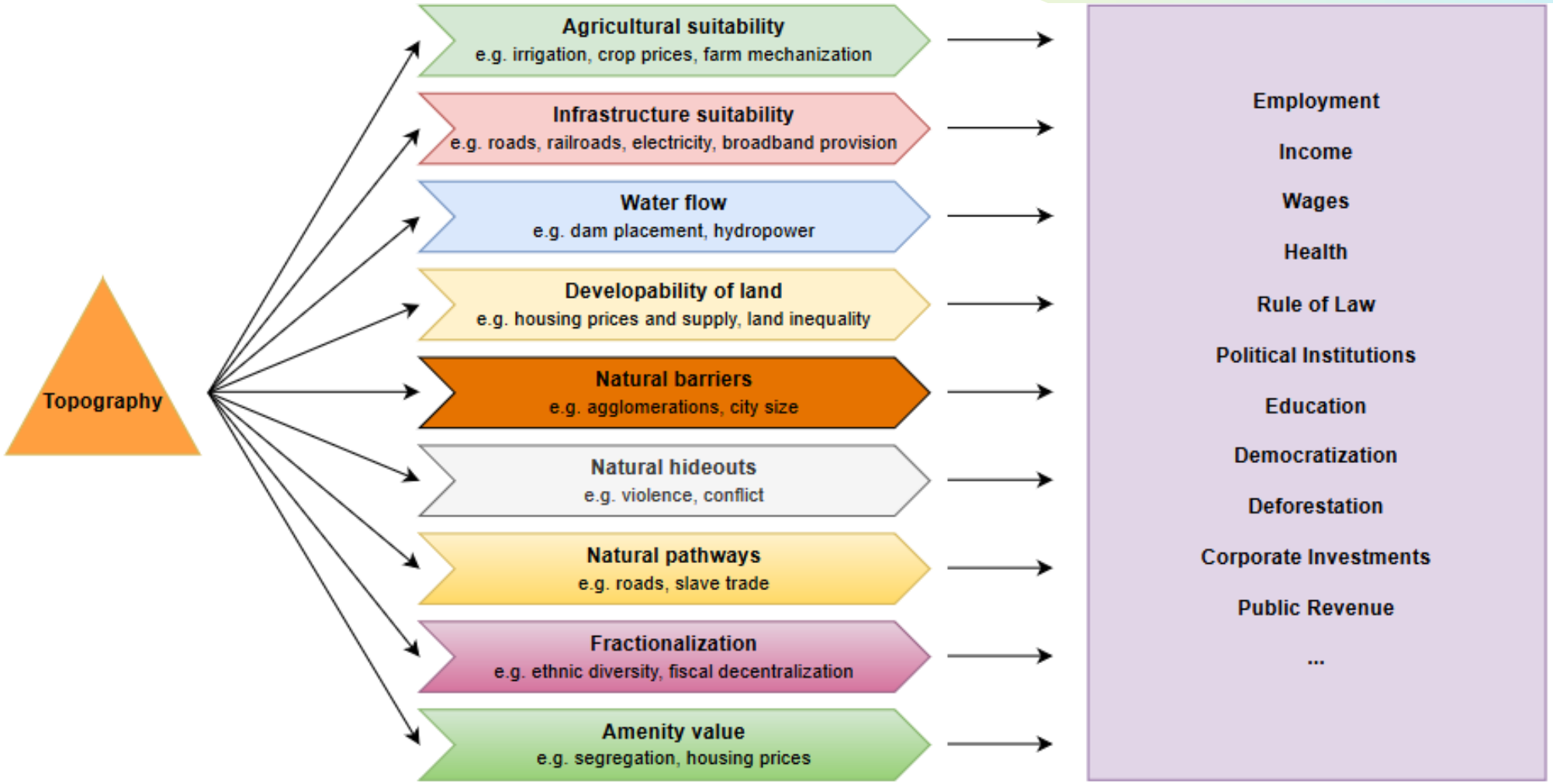


111 different pathways from topography to different outcomes

- key variable Z (used as IV in IV studies)
- instrumented variables (x)
- outcome variables (y)
- both instrumented and outcome variables (x&y)

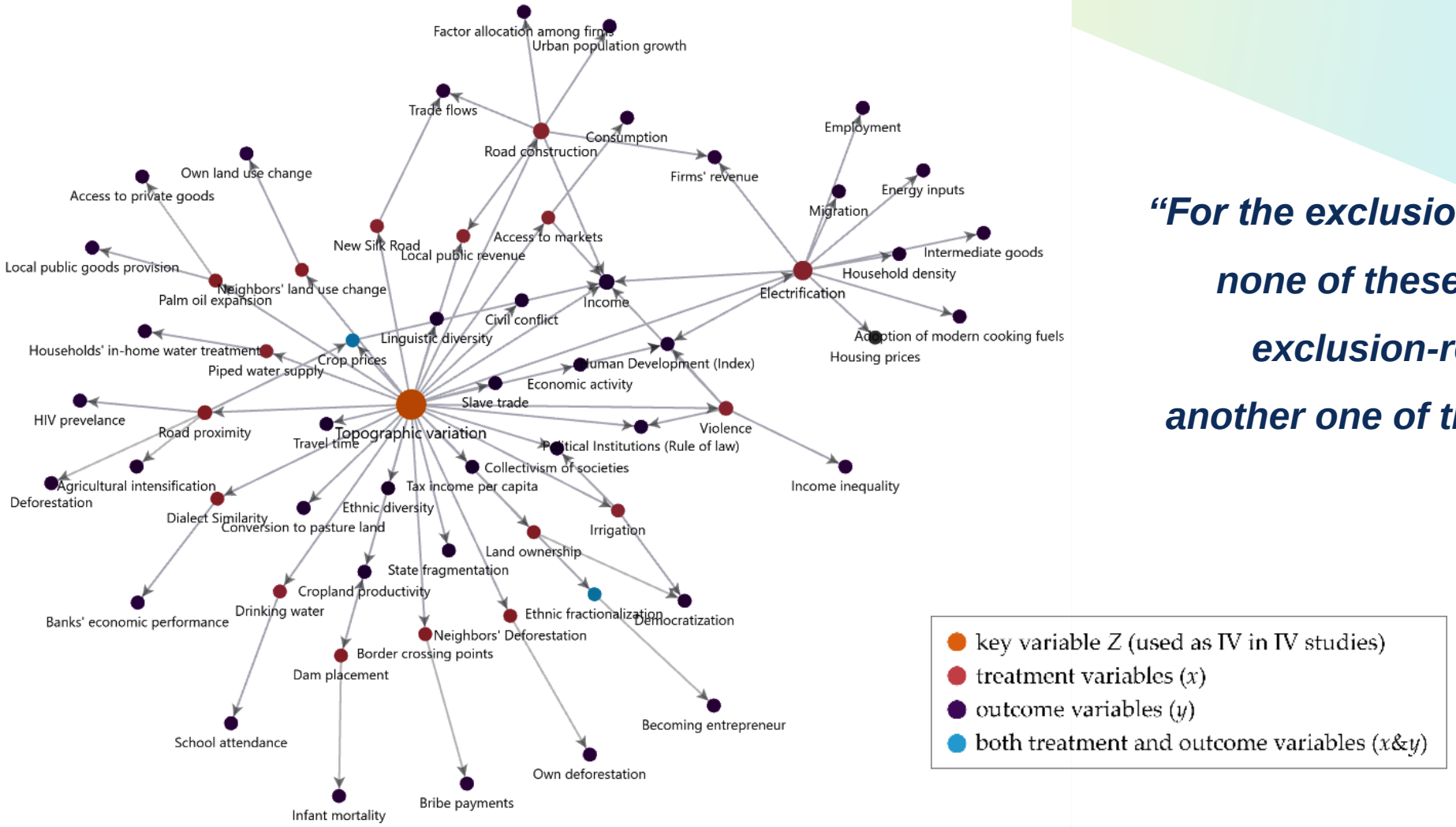
SYSTEMATIC LITERATURE REVIEW

Main pathways from topography, via mechanisms and instrumented variables to outcomes



SYSTEMATIC LITERATURE REVIEW

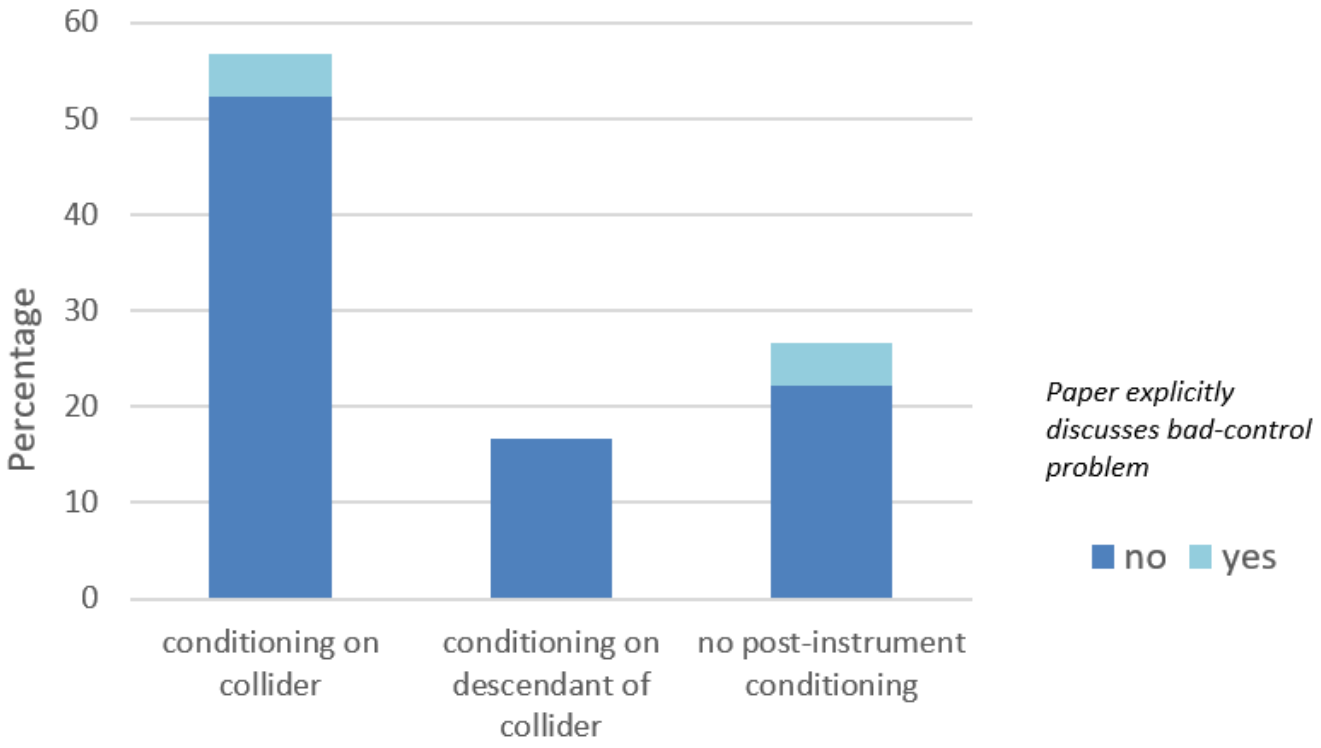
1. Causal Web - Robustness Check: Topographic IV papers from rural areas in low-income countries



"For the exclusion restriction to hold, none of these variables can be an exclusion-restriction variable, if another one of them is picked as the treatment variable"

SYSTEMATIC LITERATURE REVIEW

2. Post-instrument bias

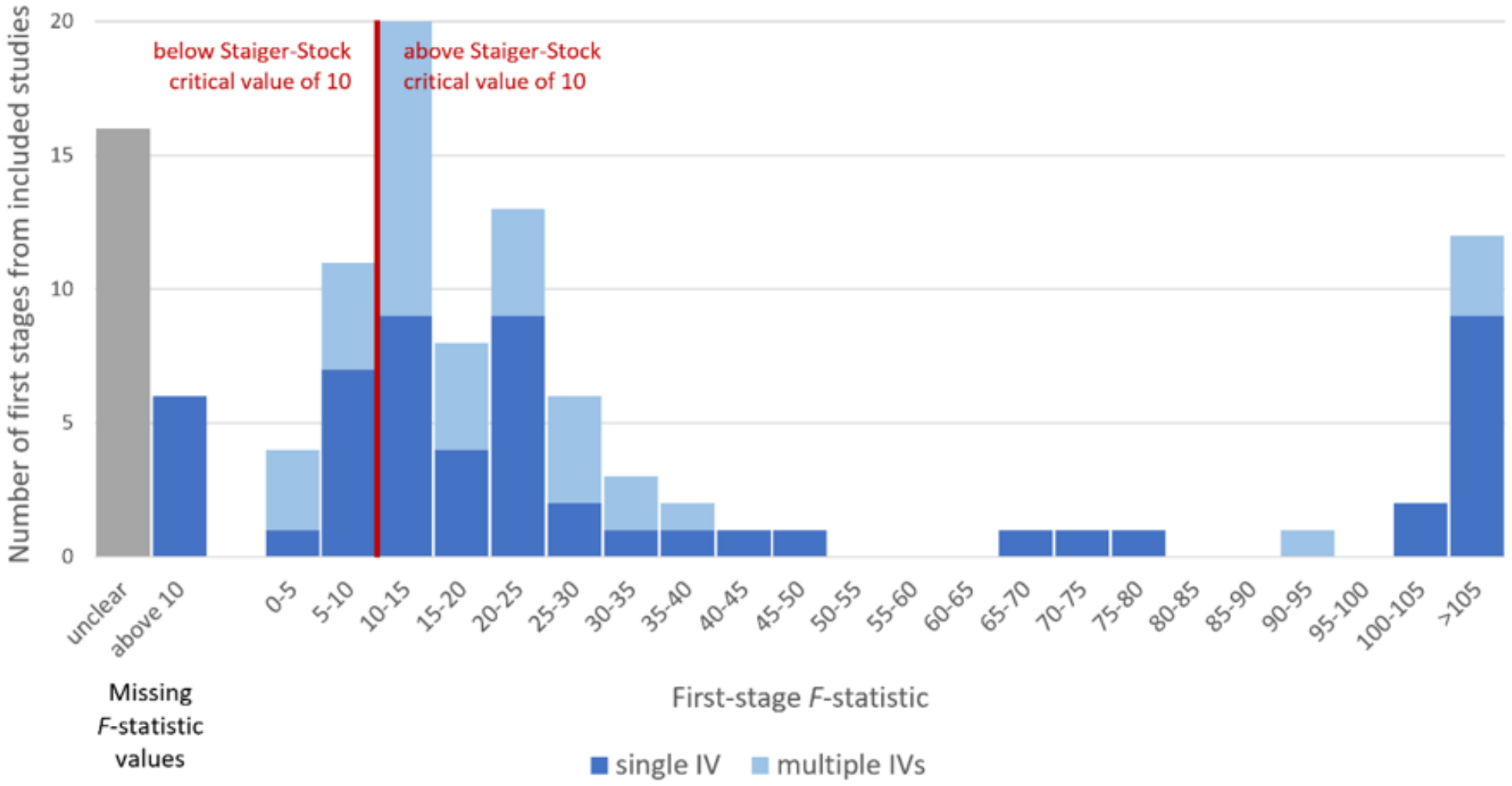


Almost 75 % of our IV studies condition on what are likely **bad controls**

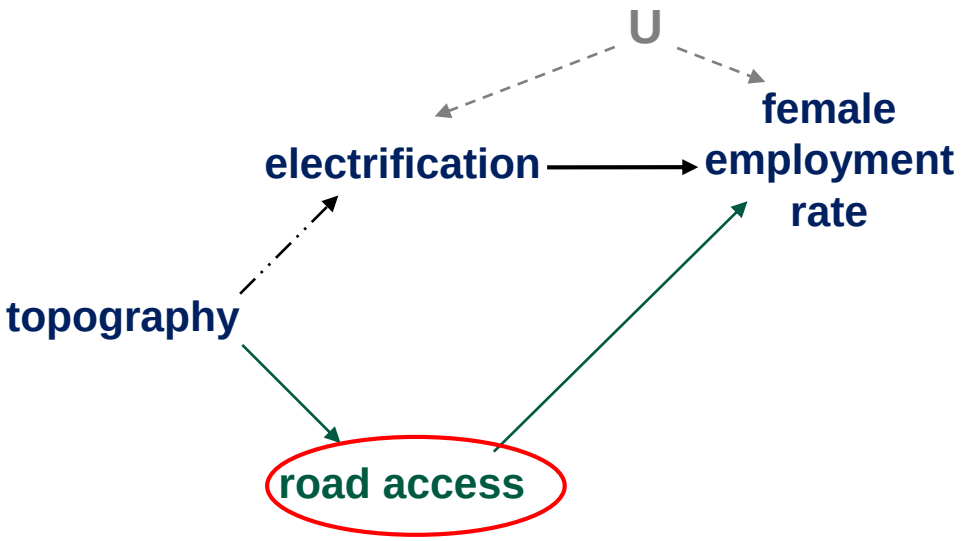
Note: The graph shows information on post-instrument conditioning for 90 of the 93 IV studies, for which the necessary information on control variables is provided in the articles. We define problematic controls as all variables from our causal web. Colliders are directly, descendants of colliders indirectly linked to topographic variation.

SYSTEMATIC LITERATURE REVIEW

4. Concomittance with IV weakness



Dinkelman (2011, AER):



- Placebo test
- Sub-sample test
- ER-treatment interaction test
- Horse Race

How to test the severity for a specific case?

Application to Dinkelman (2011)

APPLICATION TO DINKELMAN (2011)

Horse race

› comparing the **original treatment variable** (**electrification**) with the alternative (**road access**) in the spirit of a horse race – each using the other one as a control

IV results for road access as alternative treatment variable

Dependent variable	Δ female employment rate			
Estimation method	IV (gradient)			
Treatment definition	Access to roads within 5 km distance		Electrification (Dinkelman (2011)	
	(1)	(2)	(3)	(4)
Treatment	0.104*	0.106*	0.090*	0.095*
	(0.059)	(0.058)	(0.054)	(0.055)
	[0.080]	[0.069]	[0.097]	[0.083]
AR 90% Confidence Interval	{0.03; 0.29}	{0.03; 0.28}	{0.02; 0.25}	{0.02; 0.26}
Baseline controls	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Controls for other services#	No	Yes	No	Yes
First-stage results				
Gradient x 10 coefficient	-0.068***	-0.071***	-0.072***	-0.074***
	(0.026)	(0.025)	(0.024)	(0.024)
R-Squared	0.15	0.16	0.19	0.20
Partial *F*-statistic	7.11	7.77	8.34	8.26
N communities	1,816	1,816	1,816	1,816

Notes: All model specifications are equal to columns 5 to 8 of table 4 from the original study with the only difference that the instrumented variable is access to roads instead of electrification and that we excluded binary road access from the control variables while adding electrification status; robust standard errors clustered at village level in parentheses and *p*-values in square brackets.

* significant at the 10% level

Caution:

› Same post-instrument bias problem & IV weakness

CONCLUSION

- **We identify 126 studies that deliver 56 different potential exclusion-restriction variables linked to topographic variation**
  - …encompassing economically powerful variables such as infrastructure placement, population trajectories, agriculture, and housing prices

- **“Controlling-away” exclusion restriction variables is typically necessary but at the same time invalid**
  - Findings suggest that strict exogeneity assumptions might not hold in most topographical IV studies of our sample

- **Yet, no “strict proof” that topographical IVs should be excluded from the literature**
  - Findings do not disprove of any particular empirical claims from topographic-IV papers

- **Rather, the findings suggest higher standard in transparently discussing, systematically testing, and ultimately choosing to use topographic variation as an IV**
  - Our paper as contribution to provide guidance in this process

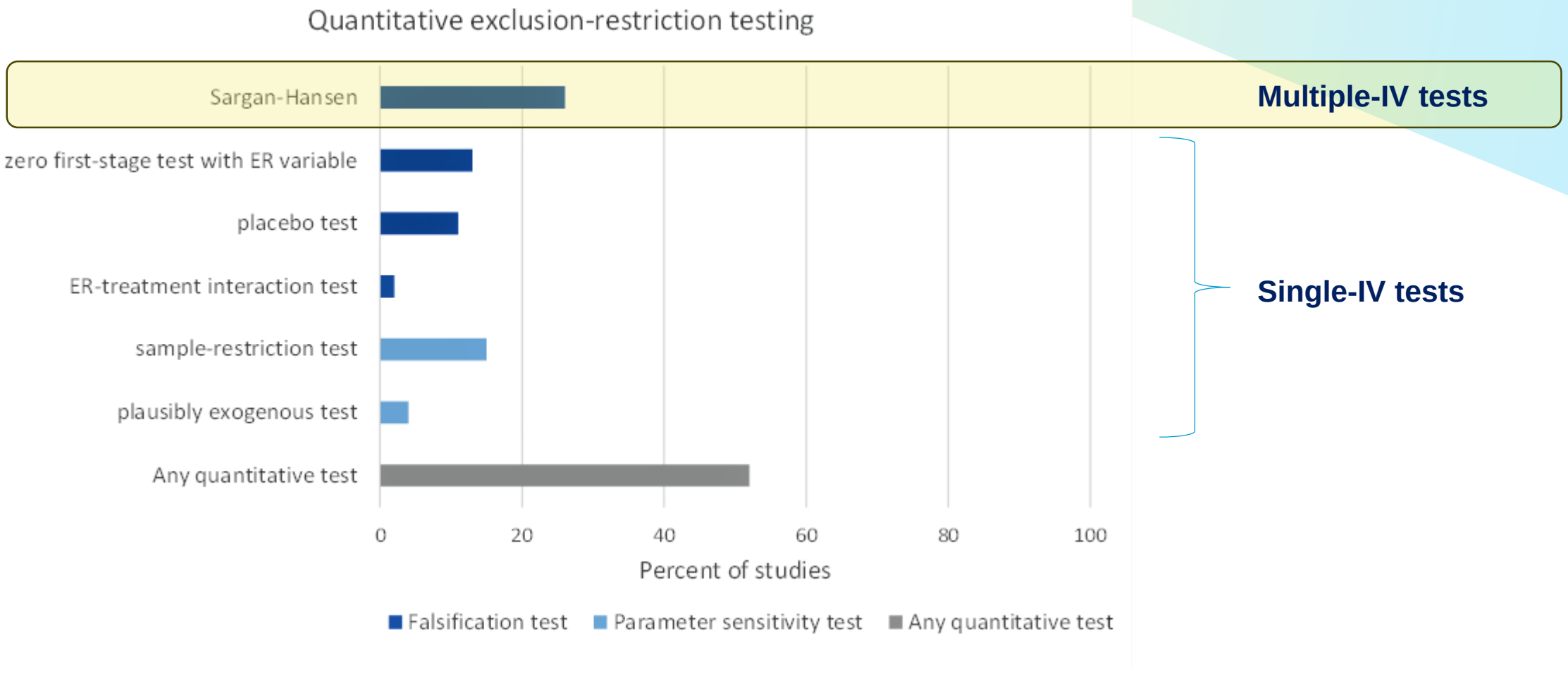
REFERENCES

- Amatulli, G., Domisch, S., Tuanmu, M. N., Parmentier, B., Ranipeta, A., Malczyk, J., & Jetz, W. (2018). A suite of global, cross-scale topographic variables for environmental and biodiversity modeling. Scientific data, 5(1), 180040.
- Bosker, M., & Buringh, E. (2017). City seeds: Geography and the origins of the European city system. Journal of Urban Economics, 98, 139-157.
- Büchel, K., & Kyburz, S. (2020). Fast track to growth? Railway access, population growth and local displacement in 19th century Switzerland. Journal of economic geography, 20(1), 155-195.
- Dinkelman, T. (2011). The effects of rural electrification on employment: New evidence from South Africa. American Economic Review, 101(7), 3078-3108.
- Djemai, E. (2018). Roads and the spread of HIV in Africa. Journal of Health Economics, 60, 118–141.
- Mellon, J. (2024). Rain, Rain, Go Away: 195 potential exclusion-restriction violations for studies using weather as an instrumental variable. American Journal of Political Science, forthcoming.
- Pearl, J. (2009). Causality. Cambridge University Press.
- Glynn, A., M. Rueda, & Schuessler, J. (2024). Post-instrument bias in linear models. Sociological Methods and Research, forthcoming.
- Felton, C., & Stewart, B. M. (2024). Handle with Care: A Sociologist's Guide to Causal Inference with Instrumental Variables. https://doi.org/10.31235/osf.io/3ua7q (version 5).

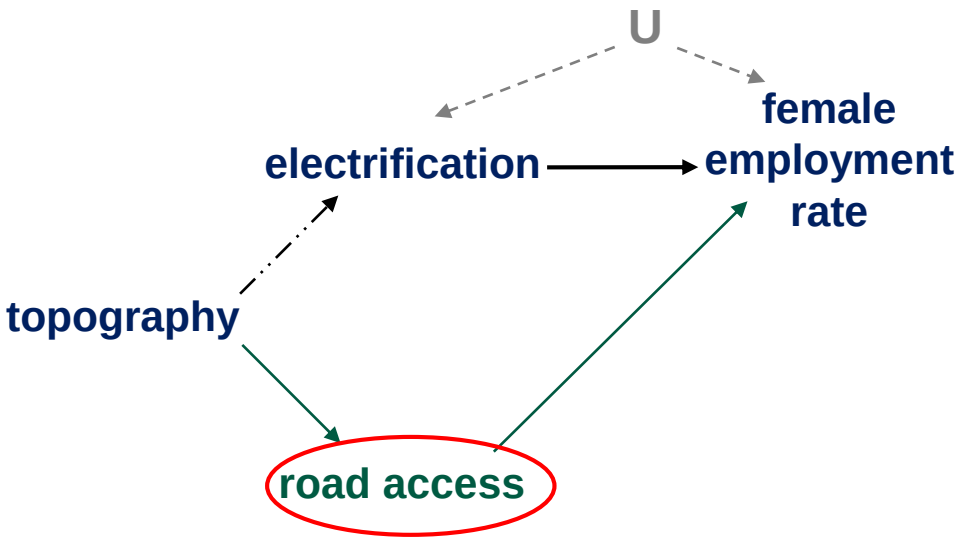
SUPPLEMENTARY MATERIAL

SYSTEMATIC LITERATURE REVIEW

3. Use of quantitative tests to validate the exclusion restriction



Dinkelman (2011, AER):



- Placebo test
- Sub-sample test
- ER interaction test
- Horse race test

How to test the severity for a specific case?

Application to Dinkelman (2011)

APPLICATION TO DINKELMAN (2011)

Placebo experiment for effect of land gradient on the female employment rate

- **"zero-first-stage"** test
- **direct effect of the IV** on the outcome in a population **where effect is expected to be absent**

Reduced form regression of female employment rate on land gradient in placebo areas

Dependent variable	Δ female employment rate			
Estimation method	OLS			
Sample	Areas electrified before 1996		Non-electrified communities (no Eskom project)	
	(1)	(2)	(3)	(4)
Land gradient x 10	-0.001	-0.001	-0.007*	-0.007**
	(0.001)	(0.001)	(0.0004)	(0.0004)
	[0.36]	[0.43]	[0.07]	[0.05]
Baseline controls	Yes	Yes	Yes	Yes
District FE	Yes	Yes	Yes	Yes
Controls for other services#	No	Yes	No	Yes
R^2	0.068	0.106	0.065	0.081
N communities	373	373	1,451	1,451

WHAT WE DO IN THIS PAPER (EXCERPT)

→ How problematic is the repeated use of the same IV in general?

- Theoretical framework
  - Exclusion Restriction violations
  - Post-instrument bias

→Do we see such repeated use for topographic IVs?

- Systematic literature review
  - The causal web of Topography
  - Prevalence of post-instrument bias
  - How do authors defend the exclusion restriction?

→ How to test the severity for a specific case?

- Application to Dinkelman (2011)
  - Bias analysis

WHAT WE DO IN THIS PAPER

→ How problematic is the repeated use of the same IV in general?

- Theoretical framework
  1. Exclusion Restriction violations
  2. Post-instrument bias
  3. Concomitance with weak IVs

→Do we see such repeated use for topographic IVs?

- Systematic literature review
  1. The causal web of Topography
  2. Prevalence of post-instrument bias in our sample
  3. How do authors defend the exclusion restriction?
  4. Prevalence of weak IVs in our sample

→ How to test the severity for a specific case?

- Application to Dinkelman (2011)
  - Bias analysis

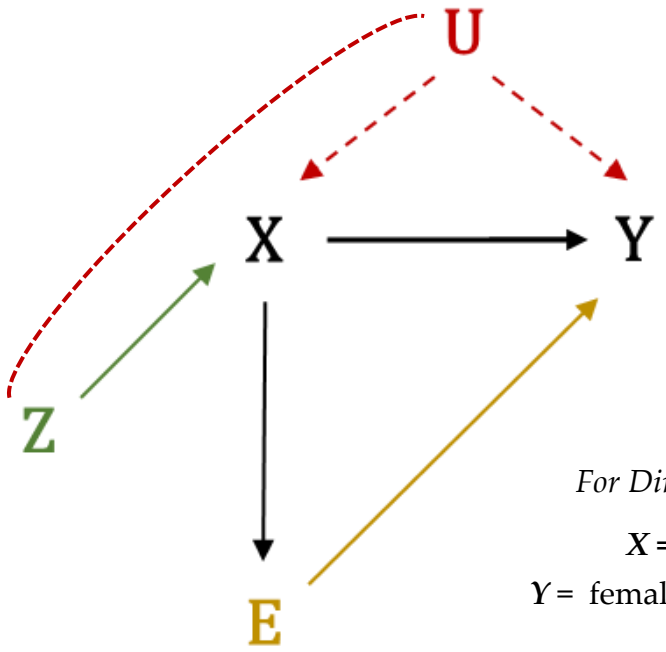
RELATED LITERATURE

- Mellon‘s review (2023) of **289 social science studies** reveal **195 variables** linked to weather
- Gallen & Raymond (2023) find **six groups of commonly-used instruments** (e.g. rainfall, sibling structure) suggesting likely exclusion restriction violations
- Deuchert & Huber (2017) and Glynn et al. (2023) point towards **bad control problems** in IV analysis
- Felton & Steward (2022) highlight bias sensitivity to even minor **violations** of the exclusion restriction in a **weak-instrument** setting

THEORETICAL FRAMEWORK

Post-instrument bias

b) *E* is a descendant of a collider



For Dinkelman (2011):

X = electrification

Y = female employment rate

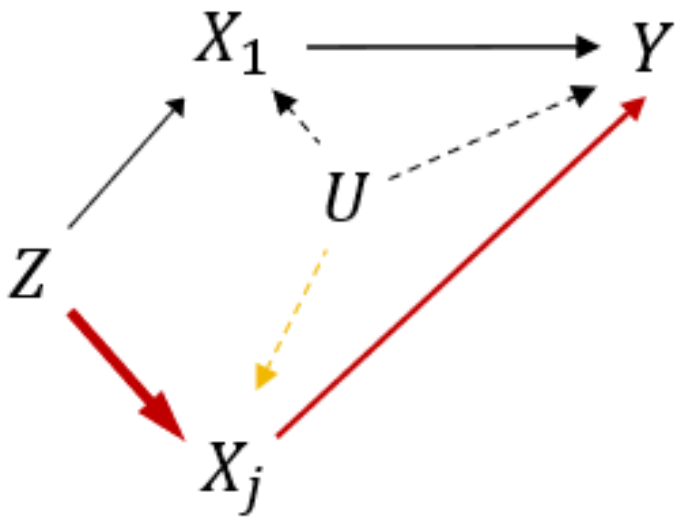
Z = land gradient

E = entrepreneurial opportunities

- Conditioning on **descendants of a collider** imports similar problems of unconfoundedness (Glynn et al., 2023)
- Solution: not control for E! (Cinelli et al., 2022; Glynn et al., 2023)
- **Yet, it might be plausible that many (topographic) IV studies condition on colliders and their descendants…**

THEORETICAL FRAMEWORK

Exclusion restriction violation & concomitance with IV weakness



For Dinkelman (2011):

X = electrification
Y = female employment rate
Z = land gradient
D = road access
V = business potentials

- **Weak instruments excaberate biases** from Exclusion Restriction violations (Felton & Steward 2022)

→ ***"Identification bias"*** (Felton & Steward 2022)

- Note: **Weak-IV robust AR confidence intervals** do not provide a panacea here (Andrews et al. 2019)

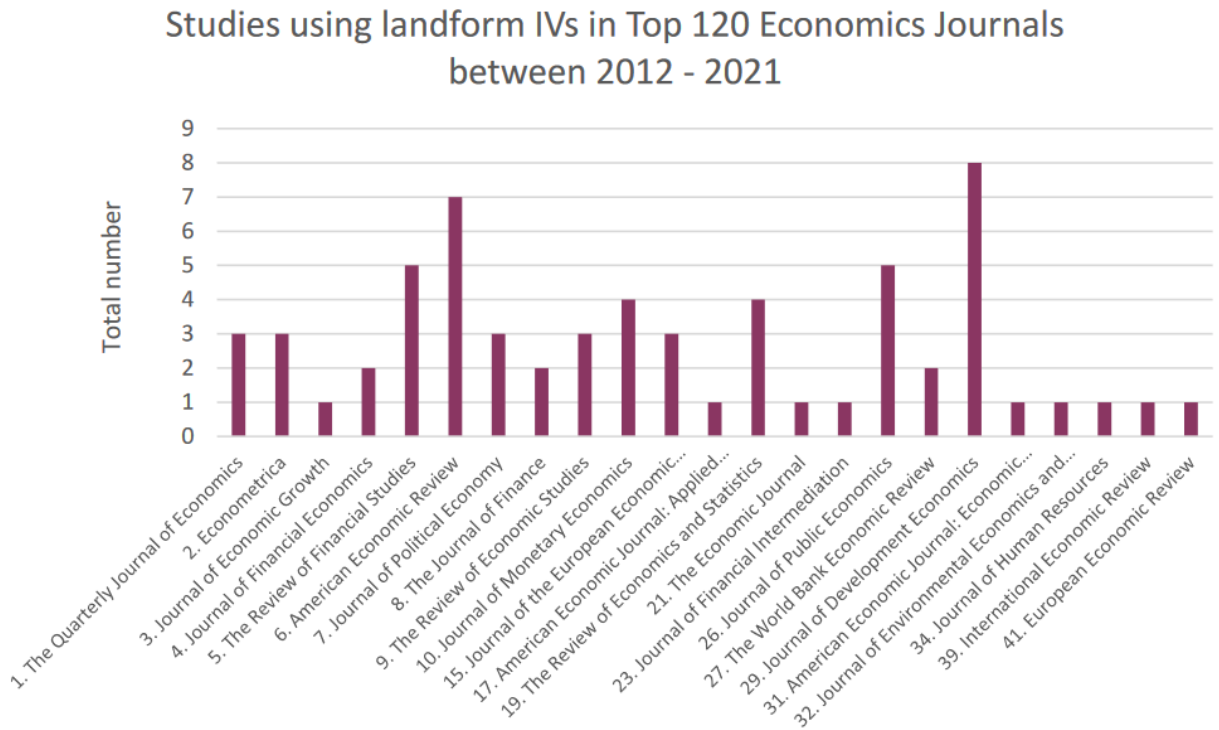
DESCRIPTIVES ON STUDIES OF SYSTEMATIC REVIEW

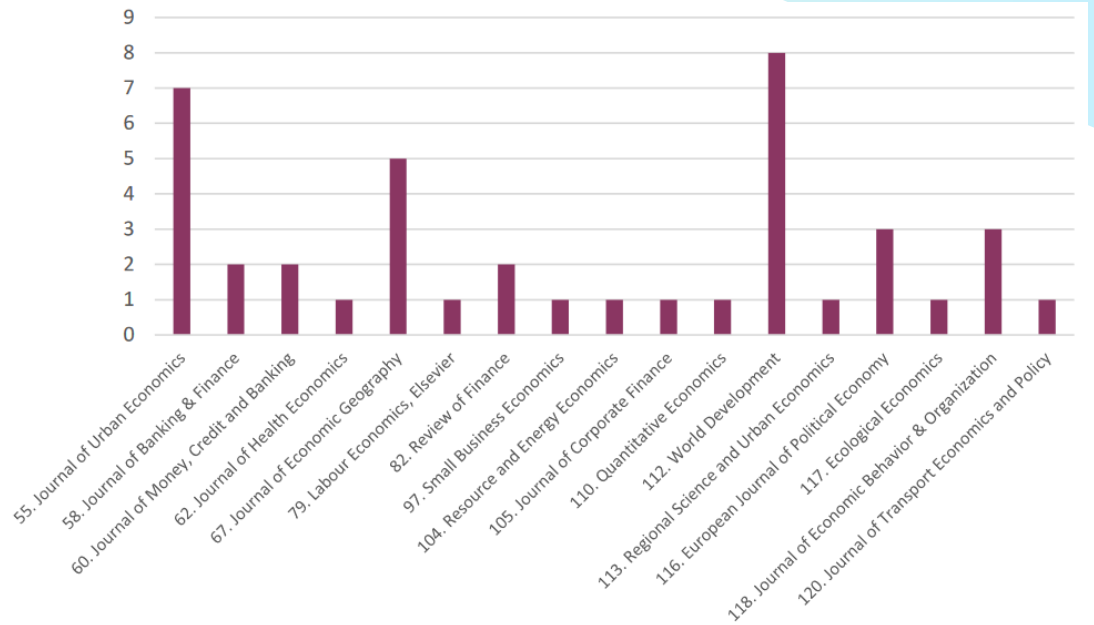
Table 1: Descriptive statistics on studies included in systematic review

	IV	reduced form		IV		IV	reduced form
Year of publication, %			**Purpose of IV, %**		**Mechanisms mentioned, #**		
2012-2016	43	48	main specification	73	water flow	7	0
2017-2021	57	52	robustness check	27	agricultural suitability	9	11
					infrastructure suitability	25	4
Journal ranking, %			**Number of IVs, %**		developability of land	46	10
among top-10 journals	32	24	single IV	64	natural barriers	5	3
			multiple IVs	36	natural hideouts	3	0
Country context w.r.t. income, %			**IV composition‡, %**		natural pathways	3	16
higher/ upper-middle	59	52	IV with topographic-variation components only	11	fractionalization	4	3
low/ lower-middle	30	30			amenity value	1	2
both	11	18					
Rural context, %	44	45	IV including non-geographic components	72			
Number of studies	93	33	Number of studies	93	Number of mentions	103	49

Note: ‡ 'Topographic-variation components only' means that the IV does not include other geographic or economic components.

JOURNAL DISTRIBUTION





SYSTEMATIC LITERATURE REVIEW

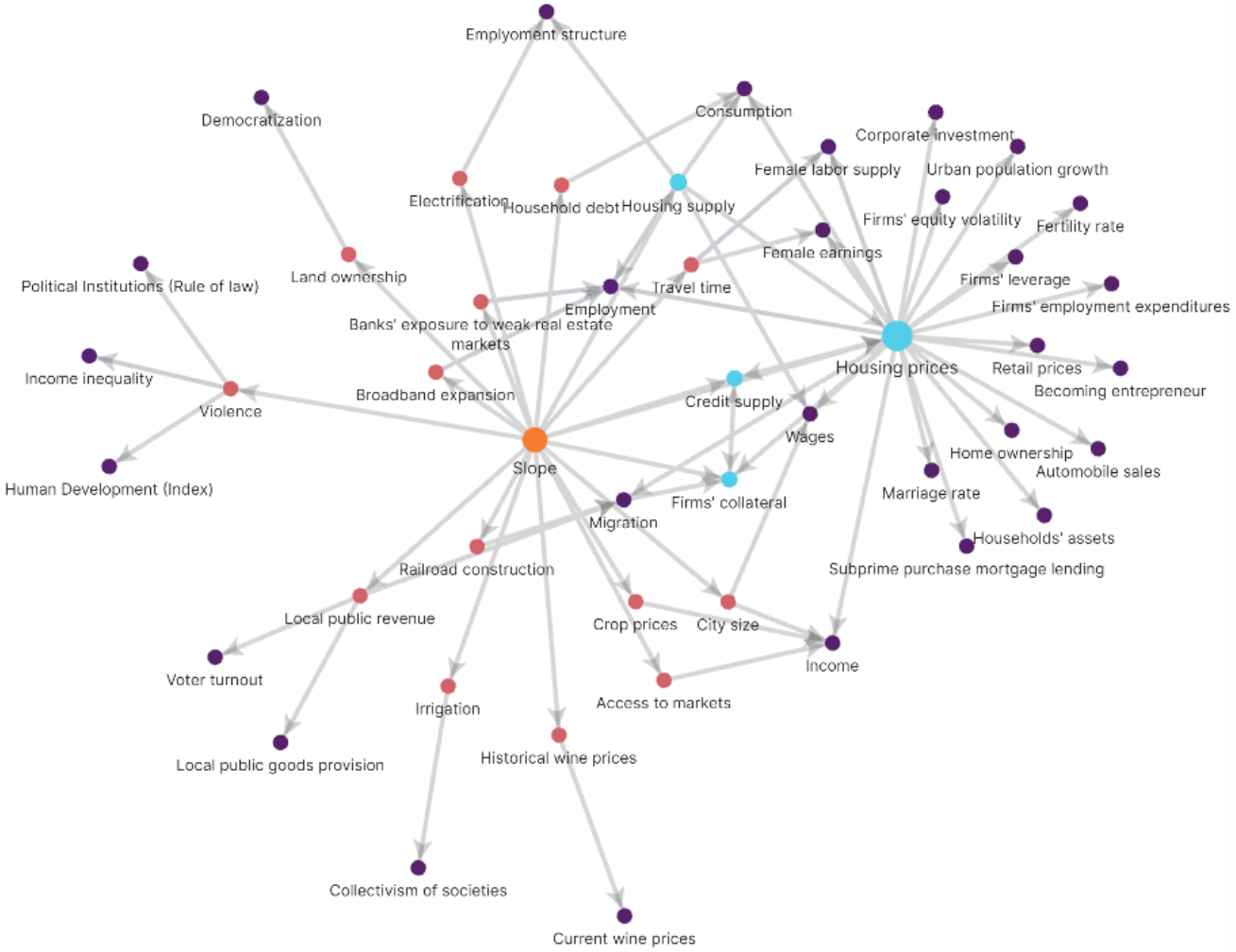
Robustness Check

a) Land gradient/ slope IV studies from low-income countries

b) Ruggedness / elevation IV studies from low-income countries

APPENDIX

Slope IV studies from high-income countries

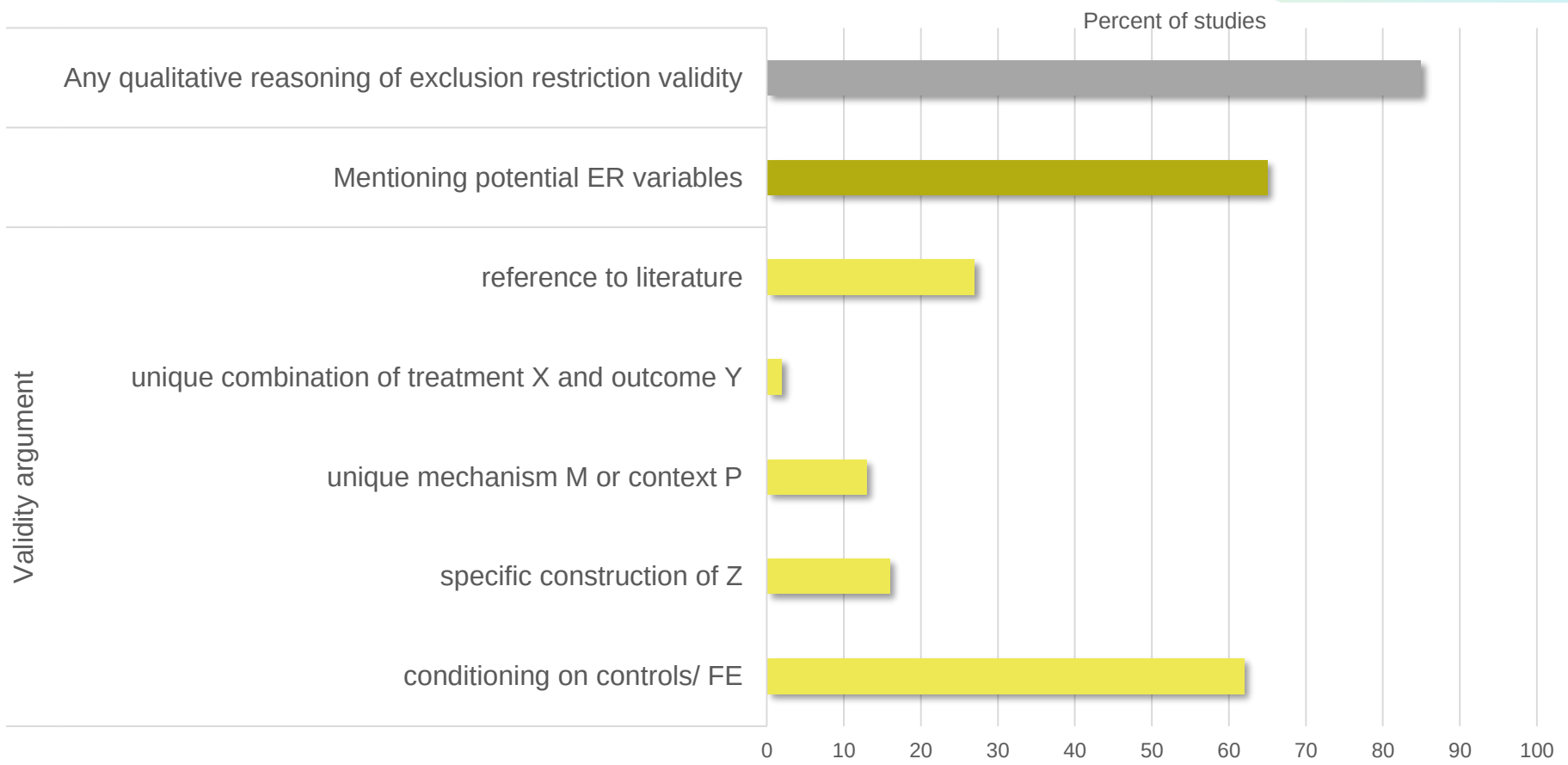


Ruggedness/ elevation IV studies from high-income countries

Urban low-income context

Rural high-income context

3. Qualitative exclusion restriction reasoning



APPLICATION TO DINKELMAN (2011)

Sample-isolation test

- test that seeks to isolate a **sub-sample** from the sample populatior with no **road access**
- Dinkelman (2011) excludes communities **directly cut by a major national road**
- More appropriate measure of **road access** for African context:

  5 km distance (Raballand et al. 2010)
- …for which electrification effect becomes insignificant

IV estimates of electrification effect on employment, by maximum distance to roads of communities excluded from the sample